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TIDAL CURRENTS AT INLETS IN THE UNITED STATES

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HYDRAULICS DIVISION

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TIDAL CURRENTS AT INLETS IN THE UNITED STATES

Joseph M. Caldwell,[1] M. ASCE

SYNOPSIS

Tidal currents at inlets along the coasts of the United States are classified into three basic types and tabulations made of each type showing the pertinent tide and current data. The hydraulic characteristics of the three types are discussed and rudimentary formulas giving the basic variables controlling the inlet velocities are set forth.

The understanding of currents at tidal entrances is complicated by the fact that most tidal bodies, particularly those inshore, are irregular in shape, and by the fact that the water surface slope is constantly changing over the tidal cycle. As a result of these complicating factors, no theory of tidal current estimation has yet been advanced which has found general acceptance by the engineering profession. Promising work on tidal current theory is now under way both in the United States and abroad, and papers describing both U.S. practice and European practice were presented at the annual meeting of the ASCE in New York in October, 1954.

As a result of the complexity of the tidal current prediction problem, reliance has chiefly been placed on field measurements and tidal model studies to obtain a reliable picture of tidal currents in inlets, bays, and estuaries around the U.S. coasts. The expense connected with either of these two methods has greatly restricted the amount of tidal current information available as compared to the tidal range information available.

The relative complexity of the range and current pictures is illustrated by the fact that a single tide gage, say in the Hudson River, can furnish fairly accurate tide readings applicable to several miles upstream and downstream and across the river, while current information is applicable over a much more restricted area. In fact that current pattern (velocity and direction) may change markedly at points as close together as 100 or 200 feet in a transverse direction. Or, even more significantly, the surface velocity pattern may vary significantly from the velocity pattern at various depths at the same location.

In defining the current velocity patterns in San Francisco Bay in 1923, the Coast and Geodetic Survey occupied twenty-eight current stations in the entrance area within 5 miles of the Golden Gate Bridge. During the survey, the control station was occupied continually while the secondary stations were occupied for at least 13 consecutive hours and for 25 consecutive hours on the more important stations. To cover the Bay area as far north as Carquinez Strait, a total of five control stations and 53 secondary stations were occupied.

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Even this expensive survey gave only a few hours observations at any station except the five control stations. Tidal current predictions based on these observations are correspondingly less accurate than tide predictions over the same area. The introduction of automatic radio-reporting secondary stations (the Roberts Current Meter) developed by the Coast and Geodetic Survey is a move to increase the scope and decrease the cost of tidal current surveys.

The Current Tables of the Coast and Geodetic Survey generally give the tidal current velocity and direction at strength of flood and ebb for some significant point in the navigation channel of the estuary or harbor and the user is warned that, "The relation of current to tide is not constant, but varies from place to place, . . ."

Three simplified versions of tidal current phenomena at tidal entrances can be described to show what might be called the extreme conditions. For the first class, assume a uniform channel gradually decreasing in cross-section and depth from the tidal entrance to the head of tide-water and with its length significantly greater than one-fourth the length of the tide wave in the estuary. Under these conditions (as shown on Fig. 1) the tidal wave propagates itself up the estuary with little change in form at the entrance and the tidal water enters the estuary in consonance with the velocities associated with the wave form. The dynamics of the wave form are such that the strength of flood can be expected at high tide and strength of ebb can be expected at low tide. Correspondingly, the slack waters can be expected at mid-tide. Mathematically the current curve might be said to be in phase with the tide, as strength of flood and high tide occur simultaneously.

The second class is a special case of the first type of estuary when the length of the tidal portion of the estuary is shorter than one-fourth the length of the tidal wave in the estuary. This condition is illustrated on Fig. 2. In this case, assuming no undue constriction at the entrance and that the length of the estuary is significantly less than one-fourth of the length of the tidal wave, the wave characteristics at the entrance will be modified by the fact that the rising tide reaches the head of tidewater and, in effect, backs up to the entrance before high tide clears the entrance. The estuary, or bay, is then substantially filled coincident with the arrival of high tide at the mouth. Slack waters will then occur at or near high tide and low tide with strengths of flood and ebb occuring at or near mid-tide. The current in this case may be said to lead the tide by 90° as strength of flood at the entrance precedes high tide by one-fourth of a tidal cycle (about 3 hours for a semi-daily tide).

As might be suspected, many inlets are somewhere between Class 1 and Class 2 in that the estuary length approximates one-fourth of a tide wave length. In the intermediate cases the relative phase of the tide and current lies somewhere between the in-phase condition and the 90° leading current, i.e., for the average case will be about 1 hour 30 minutes out of phase.

The length of the tidal wave in an estuary can be computed approximately from the formula:

$$L = 48.1 \sqrt{d}$$

where L is the length in miles of a 12 hour 25 minute tide wave (high tide to high tide) and d is the mean depth in feet along the estuary. The following table presents a set of calculations based on this formula.

For the third class of inlet, assume a large, deep bay or estuary connected to the ocean by a short but very inadequate inlet, that is, assume that the inlet is so inadequate that the tide range in the bay is only a small fraction of the tide range in the ocean. Under these conditions, the time of strength of

Table 1

Length of Tide Wave in Estuaries

Mean depth, in ft.	Length of wave, in miles	One-fourth length of wave, in miles
3	83	21
5	108	27
8	136	34
10	157	39
12	167	42
15	186	46
20	215	54
25	240	60
30	264	66
50	340	85
75	416	104
100	481	120

current in the inlet will tend to coincide with the times of high and low tide because the maximum hydraulic gradient will exist through the inlet at these times. This condition is illustrated on Figure 3. Mathematically it could be said that the tide and current curves are in phase for this condition. Under these conditions, it is also to be recognized that the maximum velocity could be approximated from the basic formula $V = \sqrt{2gh}$. As an example, a maximum tidal differential between ocean and bay of 1 foot, could be expected to produce a maximum current velocity of about 8 ft. per second. This 1-foot differential could result from a two-foot tide range in the ocean and an insignificant tide in the bay. Attention is called to the fact that the inadequate entrance (Class 3) produces the same tide-to-current phase relationship as Class 1, that of an adequate entrance to a long estuary.

The three conditions of classifications described above are seldom encountered in such simplified form in practice. Instead, we find a wide assortment of conditions in nature, some tending toward the first class, some toward the second, and some toward the third. Though a study of the configuration of a selected estuary or inlet area in light of these classifications might give some indication of the type of currents to be expected in the inlet or estuary, field observations are at present generally relied upon to establish the magnitude of the velocities and the relative phase of the tide and current. Also, the questions of basin resonance to the tidal period and reflection of tides from the head of the estuary are not considered.

An examination of the coastline of the United States shows a variety of inlet and estuary conditions coupled with widely different tidal ranges as discussed in the first part of this paper. Many inlets and estuaries around our coasts have in one way or another accumulated an excess of sand at the mouth and littoral movement along the coast is tending to force more sand into the inlet. As a result the inlets are constantly resisting an attempt on the part of the littoral drift to choke off the opening. This choking off, in turn, tends to upset the tide-to-current relationship and convert a Class 1 or Class 2 inlet into a Class 3 inlet. The velocities which the inlet must develop to prevent closure are then to an extent governed by the balance between the rate of littoral drift moving into the inlet and the ability of the inlet currents to move the sand. If the overall hydraulic characteristics of the inlet and the tide wave are unfavorable and the rate of drift sufficiently high, the inlet moves into the third category—an inadequate entrance—and the inlet may actually be sealed off by the littoral drift. This sealing off has been the case with

Moriches Inlet on the south shore of Long Island, numerous inlets along the barrier beach of Albemarle Sound, and small inlets along the northern California and Oregon coasts.

In order to illustrate the above classification of inlets, all tidal entrances, for which both tide and current data are listed in recent editions of the Tide Tables and Current Tables of the Coast and Geodetic Survey, were studied. The inlets were then classified into Case 1, Case 2, or Case 3 and the pertinent data tabulated on Tables 2, 3, and 4 respectively. The classification was made on the basis of the following requirements:

Class 1:

a) Strength of flood preceding high tide by less than one hour.

b) Tide range inside the inlet substantially equal to tide range outside the entrance. (This inside tide range was generally taken at a point several inlet widths back from the inlet or well back in the tributary bay or lagoon.)

Class 2:

a) Strength of flood preceding high tide by from 2 hours to 3 hours.

b) Tide range inside the inlet substantially equal to tide range outside the inlet.

Class 3:

a) Strength of flood preceding high tide by less than 1 hour.

b) Tide range inside the inlet only a small fraction of the range outside.

A fourth table was also prepared listing as Class 4 all inlets in which the strength of current preceded high tide by from one to two hours, this condition being intermediate to Class 2 and Classes 1 or 3.

From these tables, it is seen that of the fifty-two inlets on which sufficient data was available to justify making an entry, forty-four fell definitely in one of the three classes. Of even more significance is the fact that those inlets placed in Class 1 on the basis of the stated requirements, all but two showed an effective length of tidewater equal to or greater than the estimated 1/4 tide wave length in the estuary. These two exceptions, Cape Fear River and Tampa Bay, both showed a length ratio of 0.70. In this connection, it should be pointed out that the figure for "estimated effective depth" in the estuary, on which the estimate of tide wave length is based, is not a numerical calculation but is a mental estimate made directly from the Coast and Geodetic Survey charts. Although no great accuracy is claimed for the estimates, they are considered to be sufficiently accurate for use in the tables.

Of the 26 inlets placed in Class 2 on the basis of the stated requirements, all except two showed an effective tidewater length which was a minor fraction of the estimated 1/4 tide wave length. The two exceptions, Ossabaw Sound and Lake Worth, showed 0.55 and 0.62 respectively.

The significant feature of the eight inlets placed in Class 3 by the stated requirements is that in each case where the inside/outside tide ratio was less than 0.50, strength of flood led high tide by less than one hour. This substantiates the reasoning relative to Class 3 inlets that an inadequate inlet, as evidenced by a low inside/outside tide ratio, will show tidal currents in phase with the tide. The tidal length of the bay or estuary is of little significance in this class of inlet.

Another factor of interest with respect to the Class 3 inlets is that each of the inlets listed in Table 4 is somewhat difficult to maintain for navigation due to the relatively high rates of littoral drift in the areas, indicating, as was discussed previously, the tendency of the drift to choke off the inlet. In most

cases this action has apparently converted a Class 2 inlet into a Class 3 inlet.

Reference to Table 5 showing the Class 4, or intermediate inlets, indicates that in all cases, except Juan de Fuca Strait, the inlet is basically a Class 2 inlet which is to a significant degree choked by the sand drift at the entrance though not sufficiently to move it into a Class 3 inlet. The analysis of the action in Juan de Fuca Strait is somewhat confused by the fact that the Strait has a rear entrance to the Pacific through Georgia Strait. Attention is called to the fact that no attempt is made to classify river entrances with freshwater flows sufficiently high to distort the tidal action, such as the Mississippi and the Columbia.

Consideration of the hydraulics of the Class 1, 2, and 3 inlets shows that velocities of strength of flood and ebb are controlled basically by the following relationship:

Class 1:

$V = \sqrt{gh^2/d}$

where V = velocity in inlet at strength of flow in ft/sec.
g = acceleration of gravity ft/sec/sec.
h = tide range in feet.
d = effective entrance depth in feet.

Class 2:

$V = KA_sh/0.636\ A_e \times t$

where V = velocity in inlet at strength of flow in ft/sec.
k = ratio of maximum to average velocity in inlet cross-section.
A_s = tidewater surface area in sq. ft.
h = range of tide in bay or estuary.
A_e = area of inlet in sq. ft.
t = one-half tide period in sec.
(usually 6 hr. 12-1/2 min. = 22,350 sec.)

or, if A_s is expressed in square miles and t = 22,350 sec. and K is assumed equal to 1.2, then

$V = 2360\ A_sh/A_e$

Class 3:

$V = c\sqrt{2gh_d}$

where V = velocity in inlet at strength of flow in ft/sec.
g = acceleration of gravity in ft/sec/sec.
h_d = maximum instantaneous differential, in feet, between tide level outside and inside the inlet.
c = velocity coefficient, (assume to be 0.5 due to jet action of entrance).

It is recognized that these three formulas are only approximations which in practice are modified by other factors such as the hydraulic roughness and hydraulic efficiency of the inlet. They are presented here solely to provide a simple estimate of the basic hydraulic factors controlling the maximum velocity of flow in the tidal inlets described previously in this paper and presented in the accompanying tables.

As a check on the approximate adequacy of the formulas, the measured strength of current from the Coast and Geodetic Survey Current Tables and the computed strength of current using the applicable formula from the preceding paragraph, are listed in Tables 2, 3, and 4. The agreement appears satisfactory in most cases, though in some cases the disagreement is considerable. No attempt is made in the present paper to explain the disagreements

but it is believed that a study of more complete tide and current data, rather than just that available in the published Coast and Geodetic Survey Tables, would resolve a number of the apparent inconsistencies. Only four computations were made on the Class 2 inlets due to the difficulty of determining accurately the tide water area, A_s, from the Coast and Goedetic Survey charts.

No attempt has been made to compute the velocities to be expected in the Class 4 inlets, as a more complete treatment of tidal mechanics would be needed than is handled in this paper.

The tidal currents at major inlets around the U.S. coasts have been discussed and classified. Basic relationships controlling these currents are discussed and tabulations of inlet and current characteristics have been made. Though no comprehensive treatment of the subject is intended, possibly the tabulations will aid in the understanding of these tidal currents and their relation to engineering problems dealing with tidal entrances.

Table 2

CLASS 1: ADEQUATE ENTRANCES WITH LONG ESTUARY
Estuary One-Fourth Tide Wave in Length or Longer

(Strength of flood and high tide not over one hour apart)

Entrance	Precedence of current before tide (hrs:min)	Tide Range Out-side	Tide Range In-side	Tide Range Ratio	Est. eff. depth of estuary (feet)	Est. tide length of estuary (miles)	Est. 1/4 tide wave length (miles)	Ratio Est. len. / 1/4 tide len.	Vel. strength of tide mea. ft/sec	Vel. strength of tide com. ft/sec	Vel. strength of tide ratio mea/com
Hudson River	0:40	4.7	4.4	0.94	20	150	54	2.8	2.70	3.96	0.68
Delaware River	1:00	4.2	4.2	1.00	25	120	60	2.0	3.55	3.08	1.15
Chesapeake Bay	-0:10	2.8	2.3	0.82	40	170	75	2.3	2.03	1.90	1.07
James River	0:19	2.6	2.6	1.00	25	80	60	1.3	2.53	2.69	0.95
York River	1:05 (1)	2.3	2.5	1.09	25	60	60	1.0	2.37	1.95	1.21
Potomac River	0:15	1.3	1.5	1.15	30	108	66	1.8	0.85	0.95	0.90
Cape Fear River	1:00	4.5	4.1	0.91	25	40	60	0.7	2.53	4.65	0.55
St. John's River	0:11	4.9	4.5	0.92	20	100	56	1.8	3.55	5.08	0.70
Tampa Bay	0:39	1.3	1.5	1.15	15	30	46	0.7	1.61	1.48	1.09
San Francisco Bay (2)	1:00	3.8	4.3	1.13	40	75	75	1.0	5.41		(2)

FOOTNOTES:

(1) Included even though 5 min. over 1 hour limit.

(2) The irregularities in entrance cross-section and in the shape of the estuary preclude a reasonable application of the simplified velocity formula.

Table 3

CLASS 2: ADEQUATE ENTRANCE WITH SHORE ESTUARY APPROXIMATELY ONE-FOURTH TIDE WAVE LENGTH OR SHORTER

(Current leading tide by 2 to 3 1/2 hours)

Entrance	Precedence of current before tide (hrs:min)	Tide Range Out-side	Tide Range In-side	Tide Range Ratio	Est. eff. depth of estuary (feet)	Est. tide length of estuary (miles)	Est. 1/4 tide wave length (miles)	Ratio Est. len. / 1/4 tide len.	Vel. strength of tide mea. ft/sec	Vel. strength of tide com. ft/sec	Vel. strength of tide ratio mea/com
Portland Harbor, Me.	2:41	9.0	8.9	0.99	25	9	60	.15	1.69		
Little Harbor, Me.	2:53	8.7	8.7	1.0	25	5	60	.08	1.52		
Boston Harbor	2:58	9.3	9.5	1.02	30	8	66	.12	2.87		
East Rockaway Inlet	2:08	4.1	3.9	0.95	15	7	46	.15	3.89	3.26	1.2
Rockaway Inlet	2:47	4.9	5.1	1.04	25	11	60	.18	3.72		
Cape May Inlet	2:22	4.4	4.3	0.97	25	2	60	.03	3.38		
Beaufort Inlet	2:00	3.7	2.5	0.68	8	8	34	.24	3.72		
Charleston Harbor	2:05	5.2	5.1	0.98	30	25	66	.38	3.04		
Port Royal Sound	2:20	6.6	7.1	1.08	20	20	54	.37	3.04		
Wassaw Sound	3:05	8.1	6.8	0.84	20	11	54	.2	3.21	1.30	2.5
Ossabaw Sound	2:09	7.2	7.5	1.04	12	23	42	.55	3.04		
St. Catherine Sound	2:48	7.1	7.5	1.06	30	14	66	.21	3.38		
Sapelo Sound	3:03	6.9	7.4	1.07	15	15	46	.33	3.88		
Doboy Sound	2:38	6.8	7.2	1.06	20	10	54	.19	3.38		
St. Simon Sound	2:49	6.6	7.3	1.10	20	16	54	.30	3.38		
St. Andrews Sound	3:00	6.6	6.7	1.01	15	24	46	.52	2.03		
St. Mary River	2:;2	5.8	6.1	1.07	15	9	46	.20	4.06		
Lakeworth Inlet	2:34	2.8	1.8	0.64	6	18	29	.62	5.07		
Blind Pass, Fla.	2:02	1.8	1.5	0.81	7	1.5	32	.05	0.85		
Big Pass, Fla.	3:00	1.9	1.8	0.95	8	2.5	34	.07	1.69		
San Diego Bay	2:59	3.9	4.2	1.10	25	12	60	.20	2.36	2.47	0.95
Humbolt Bay	2:47	4.5	4.8	1.07	25	11	60	.18	3.04		
Yaquina Bay	2:25	5.9	6.2	1.05	15	15	46	.33	3.88		
Tillamook Bay	2:04	5.7	5.2	0.91	8	5	34	.15	4.73		
Willapa Bay	2:20	6.2	6.8	1.10	30	20	66	.30	4.22		
Gray's Harbor	2:40	6.9	7.2	1.04	25	26	60	.43	3.55	3.79	0.91

Table 4

CLASS 3: INADEQUATE ENTRANCES
Tide & Current in Phase and Tide Range Ratio Less Than One-Half

(Strength of flood and high tide not over one hour apart)

Entrance	Precedence of current before tide (hrs:min)	Tide Range Out-side	Tide Range In-side	Tide Range Ratio	Est. eff. depth of estuary (feet)	Est. tide length of estuary (miles)	Est. 1/4 tide wave length (miles)	Ratio Est. len. / 1/4 tide len.	Vel. strength of tide mea. ft/sec	Vel. strength of tide com. ft/sec	Vel. strength of tide ratio mea/com
Fire Island Inlet	0:27	4.1	0.7	0.17	5	18	27	.67	3.88	5.2	0.75
Barnegat Inlet	0:17	3.1	0.6	0.19	5	16	27	.59	3.88	4.5	0.86
Indian River, Del.	0:50	2.6	0.9	0.35	5	10	27	.37	3.88	3.7	0.91
Hatteras Inlet	0:10	2.0	0.5	0.25	15	24	46	.52	3.88	3.5	0.97
Ocracoke Inlet	0:15	1.9	0.5	0.26	18	50	50	1.00	2.36	3.36	0.74
Ft. Pierce Inlet	0:23	1.6	0.7	0.27	5	16	27	.59	4.73	2.7	1.75
Galveston Bay	0:43	2.0	1.4	0.60	10	30	39	.77	2.36	2.2	1.07
Aransas Pass	0:39	1.5	0.5	0.33	10	20	39	.51	1.45	2.8	0.52

Table 5

CLASS 4: INTERMEDIATE ENTRANCES AND ESTUARIES

(Entrances intermediate to classes 1, 2, and 3)

Entrance	Precedence of current before tide (hrs:min)	Tide Range Out-side	Tide Range In-side	Tide Range Ratio	Est. eff. depth of estuary (feet)	Est. tide length of estuary (miles)	Est. 1/4 tide wave length (miles)	Ratio Est. len. / 1/4 tide len.	Vel. strength of tide mea. ft/sec	Vel. strength of tide com. ft/sec	Vel. strength of tide ratio mea/com
Portsmouth, N.H.	1:53	8.7	4.6	0.53	50	15	85	.18	2.54		
Jones Inlet	1:26	3.6	2.4	0.67	10	9	39	.23	4.90		
Manasquan Inlet	1:25	4.3	3.5	0.81	5	5	27	.19	3.04		
Savannah River	1:44	6.8	6.7	1.02	15	22	46	.48	3.55		
Nassau Sound	1:51	5.4	5.0	0.94	15	23	46	.5	2.87		
Coos Bay, Ore.	1:28	5.2	4.9	0.94	25	15	60	.25	3.38		
Umpqua Bay, Ore.	1:26	5.1	5.1	1.00	15	25	46	.54	1.52		
Juan de Fuca Str.	1:23	5.8	4.2	0.73	100	175	120	1.46	1.69		

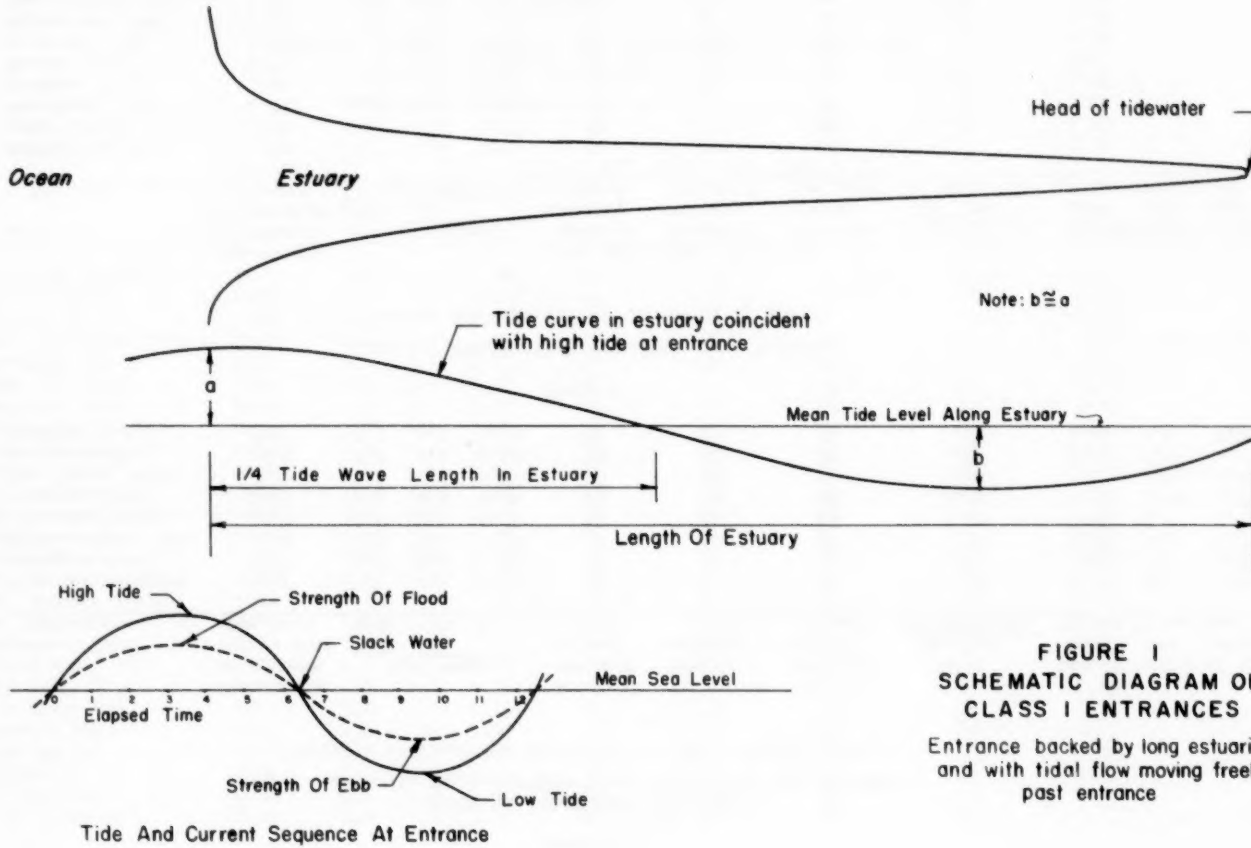

FIGURE 1
SCHEMATIC DIAGRAM OF CLASS I ENTRANCES

Entrance backed by long estuaries and with tidal flow moving freely past entrance

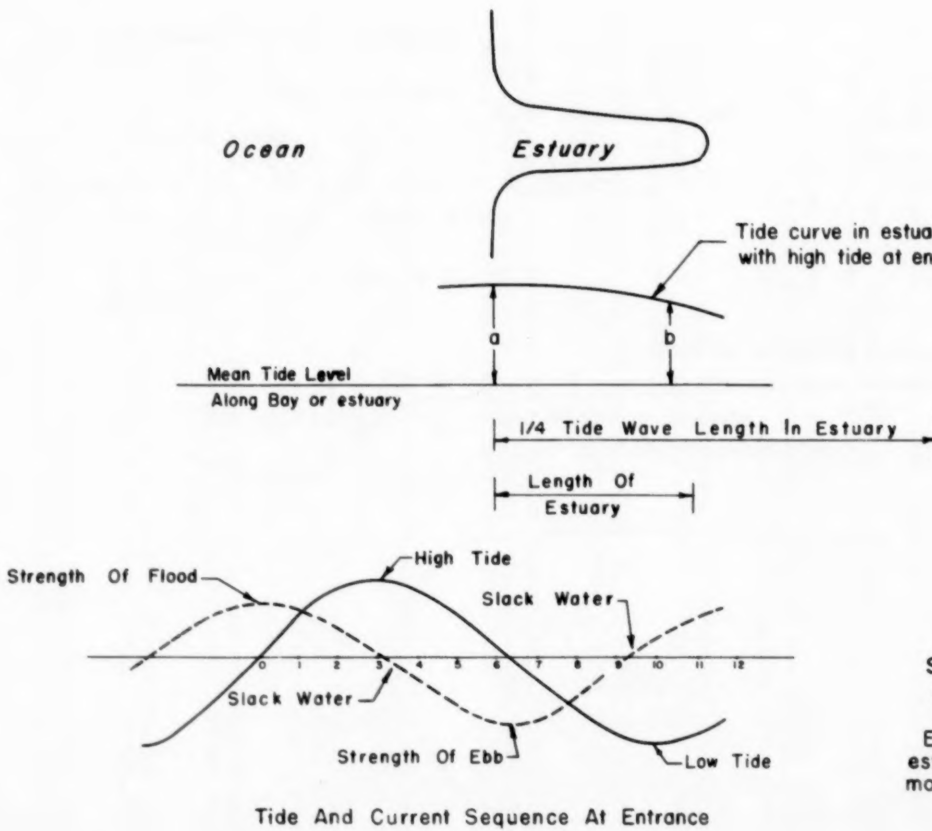

FIGURE 2
SCHEMATIC DIAGRAM OF
CLASS 2 ENTRANCES

Entrance backed by short estuary and with tidal flow moving freely past entrance

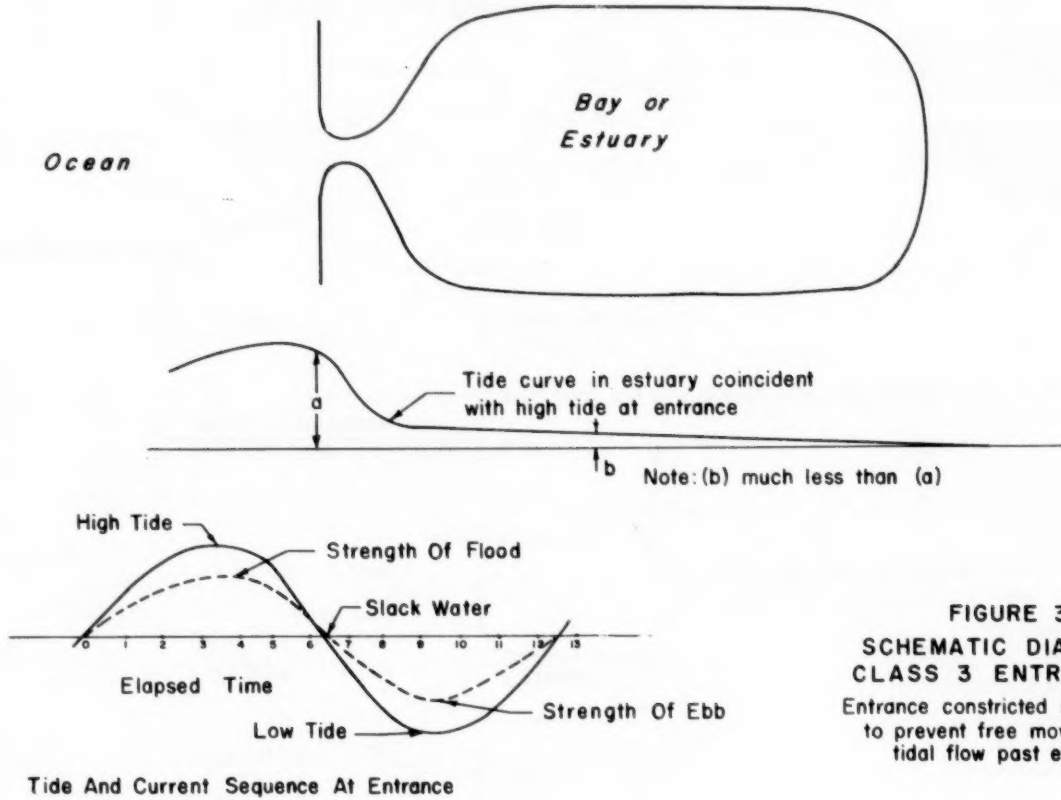

FIGURE 3

SCHEMATIC DIAGRAM
CLASS 3 ENTRANCES

Entrance constricted sufficiently to prevent free movement of tidal flow past entrance

PROCEEDINGS-SEPARATES

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DECEMBER: 558(ST), 559(ST), 560(ST), 561(ST), 562(ST), 563(ST)[c], 564(HY), 565(HY), 566(HY), 567(HY), 568(HY)[c], 569(SM), 570(SM), 571(SM), 572(SM)[c], 573(SM)[c], 574(SU), 575(SU), 576(SU), 577(SU), 578(HY), 579(ST), 580(SU), 581(SU), 582(Index).

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JANUARY: 583(ST), 584(ST), 585(ST), 586(ST), 587(ST), 588(ST), 589(ST)[c], 590(SA), 591(SA), 592(SA), 593(SA), 594(SA), 595(SA)[c], 596(HW), 597(HW), 598(HW)[c], 599(CP), 600(CP), 601(CP), 602(CP), 603(CP), 604(EM), 605(EM), 606(EM)[c], 607(EM).

FEBRUARY: 608(WW), 609(WW), 610(WW), 611(WW), 612(WW), 613(WW), 614(WW), 615(WW), 616(WW), 617(IR), 618(IR), 619(IR), 620(IR), 621(IR)[c], 622(IR), 623(IR), 624(HY)[c], 625(HY), 626(HY), 627(HY), 628(HY), 629(HY), 630(HY), 631(HY), 632(CO), 633(CO).

MARCH: 634(PO), 635(PO), 636(PO), 637(PO), 638(PO), 639(PO), 640(PO), 641(PO)[c], 642(SA), 643(SA), 644(SA), 645(SA), 646(SA), 647(SA)[c], 648(ST), 649(ST), 650(ST), 651(ST), 652(ST), 653(ST), 654(ST)[c], 655(SA), 656(SM)[c], 657(SM)[c], 658(SM)[c].

APRIL: 659(ST), 660(ST), 661(ST)[c], 662(ST), 663(ST), 664(ST)[c], 665(HY)[c], 666(HY), 667(HY), 668(HY), 669(HY), 670(EM), 671(EM), 672(EM), 673(EM), 674(EM), 675(EM), 676(EM), 677(EM), 678(HY).

MAY: 679(ST), 680(ST), 681(ST), 682(ST)[c], 683(ST), 684(ST), 685(SA), 686(SA), 687(SA), 688(SA), 689(SA)[c], 690(EM), 691(EM), 692(EM), 693(EM), 694(EM), 695(EM), 696(PO), 697(PO), 698(SA), 699(PO)[c], 700(PO), 701(ST)[c].

JUNE: 702(HW), 703(HW), 704(HW)[c], 705(IR), 706(IR), 707(IR), 708(IR), 709(HY)[c], 710(CP), 711(CP), 712(CP), 713(CP)[c], 714(HY), 715(HY), 716(HY), 717(HY), 718(SM)[c], 719(HY)[c], 720(AT), 721(AT), 722(SU), 723(WW), 724(WW), 725(WW), 726(WW)[c], 727(WW), 728(IR), 729(IR), 730(SU)[c], 731(SU).

c. Discussion of several papers, grouped by Divisions.

e. Presented at the Atlantic City (N.J.) Convention in June, 1954.